

**Measurement of**  
 $Br(B^0 \rightarrow D_s^+ D^-) / Br(B^0 \rightarrow D^- \pi \pi \pi)$   
**at CDF**

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# Measurement of $\frac{Br(B^0 \rightarrow D_s^+ D^-)}{Br(B^0 \rightarrow D^- 3\pi)}$ at CDF

- Motivation
- Data sample
- Analysis challenges
- Results
- Future plans

# Motivation

Use  $Br(B_s \rightarrow D_s^{(*)+} D_s^{(*)-})$  to measure  $\frac{\Delta\Gamma_s}{\Gamma_s}$

- $B_s \rightarrow D_s^+ D_s^-$  pure CP even eigenstate
- $B_s \rightarrow D_s^{*+} D_s^{*-}$  predominantly CP even eigenstate
- Monte Carlo shows clear separation between  $D_s^+ D_s^-$  and  $D_s^{*+} D_s^{*-}$
- Reconstruct hadronic modes  $D_s^- \rightarrow \phi\pi^-(K^{*0}K^-, \pi^-\pi^+\pi^-)$

## NOT USED:

- $D_s^- \rightarrow K_s^0 K^-$  -  $K_s$  is heavily suppressed by the trigger
- $D_s^- \rightarrow \phi\pi^-\pi^+\pi^-$  - 5 tracks (8 tracks total) - suppressed by fiducial volume
- $D_s^- \rightarrow K^-\pi^+\pi^-$  - high background
- Fit CP even lifetime (provided enough statistics)
- Measure  $\frac{\Delta\Gamma_s}{\Gamma_s}$  from branching fraction

# Approach

Complex analysis measuring several ratios of branching fractions.

$$\frac{Br(B^0 \rightarrow D_s^+ D^-)}{Br(B^0 \rightarrow D^- 3\pi)}, \quad - \text{Feature Presentation.}$$

$$\frac{Br(B_s \rightarrow D_s^- 3\pi)}{Br(B^0 \rightarrow D^- 3\pi)} \quad \frac{Br(B_s \rightarrow D_s^+ D_s^-)}{Br(B^0 \rightarrow D_s^+ D^-)}$$

$D_s^- \rightarrow \phi\pi^- (K^{*0}K^-, \pi^-\pi^+\pi^-), D^+ \rightarrow K\pi\pi$  for all modes

Combine measurements for  $D_s^- \rightarrow \phi\pi^- (K^{*0}K^-, \pi^-\pi^+\pi^-)$

- Use similar 6-tracks  $B^0 \rightarrow D^- 3\pi$  and  $B_s \rightarrow D_s 3\pi$  to test tools and techniques
- $B_s \rightarrow D_s 3\pi$  - first observation, add statistics to  $B_s$  -mixing measurement
- $Br(B^0 \rightarrow D_s^{(*)+} D^{(*)-})$  could be used to measure CP phase  $\gamma$  (hep-ph/0410015)
- Measure  $\frac{Br(B_s \rightarrow D_s^+ D_s^-) / Br(B^0 \rightarrow D_s^+ D^-)}{Br(B_s \rightarrow D_s^- 3\pi) / Br(B^0 \rightarrow D^- 3\pi)}$  to remove dependence on  $Br(D_s \rightarrow \phi\pi)$

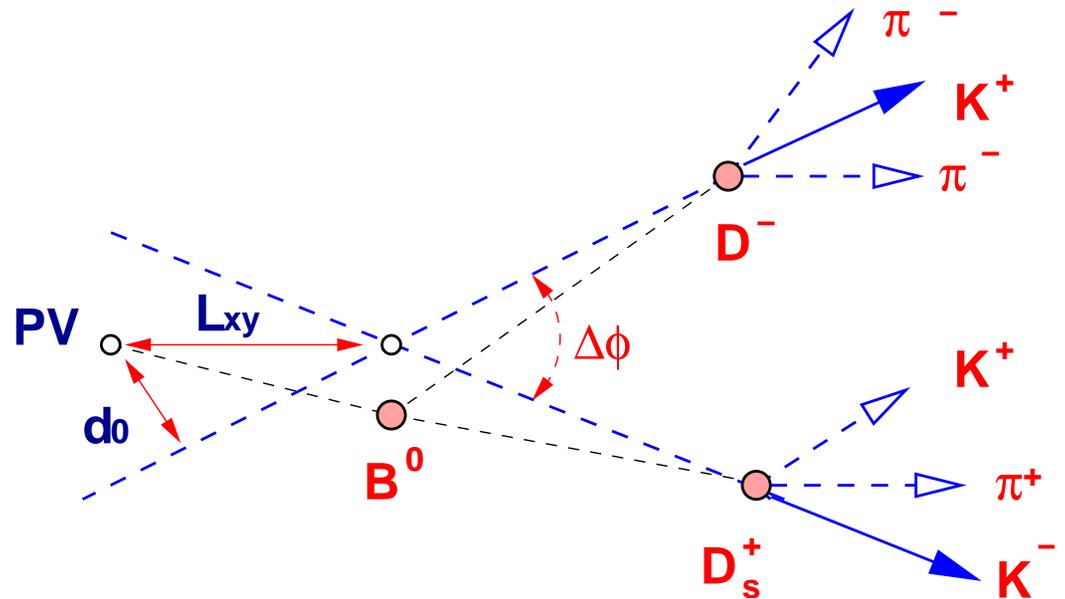
# Displaced Track Trigger Sample

## One Track Requirements

- $p_T > 2 \text{ GeV}/c$
- $120\mu < |d_0| < 1\text{mm}$

## Two Track Requirements

- Opposite charge
- $L_{xy} > 0.02\text{cm}$
- Linear Sum  $p_T > 5.5 \text{ GeV}$
- $0.0349 < \Delta\phi < 1.571$



Used Luminosity  $243\text{pb}^{-1}$

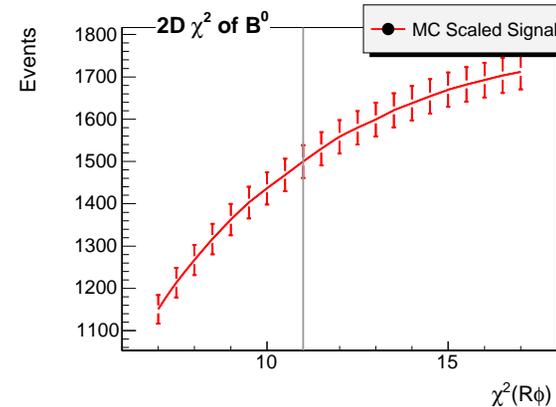
# Analysis Challenges

- Candidate selection
- Fitting background with templates
- Dealing with Self-Reflections
- Fits and yields
- Studying  $3\pi$  invariant mass for  $B^0 \rightarrow D^- 3\pi$

# Event Selection, Cut Optimization

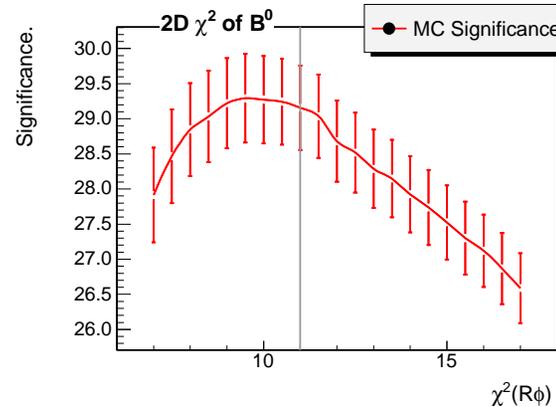
$$B^0 \rightarrow D^- 3\pi$$

	Cut Variable	Value
$B$	$L_{xy}/\sigma(L_{xy})$	$> 13$
$B$	$d_0$	$< 0.007$ cm
$B$	$\chi_{r\phi}^2$	$< 11$
$B$	$p_T$	$> 9.0$ GeV/c
$D^+$	$L_{xy}/\sigma(L_{xy})$	$> 13$
$D^+$	$L_{xy}^{\leftarrow B}$	$> 0.05$ cm



$$B^0 \rightarrow D_s^+ D_s^-, D_s^+ \rightarrow \phi\pi$$

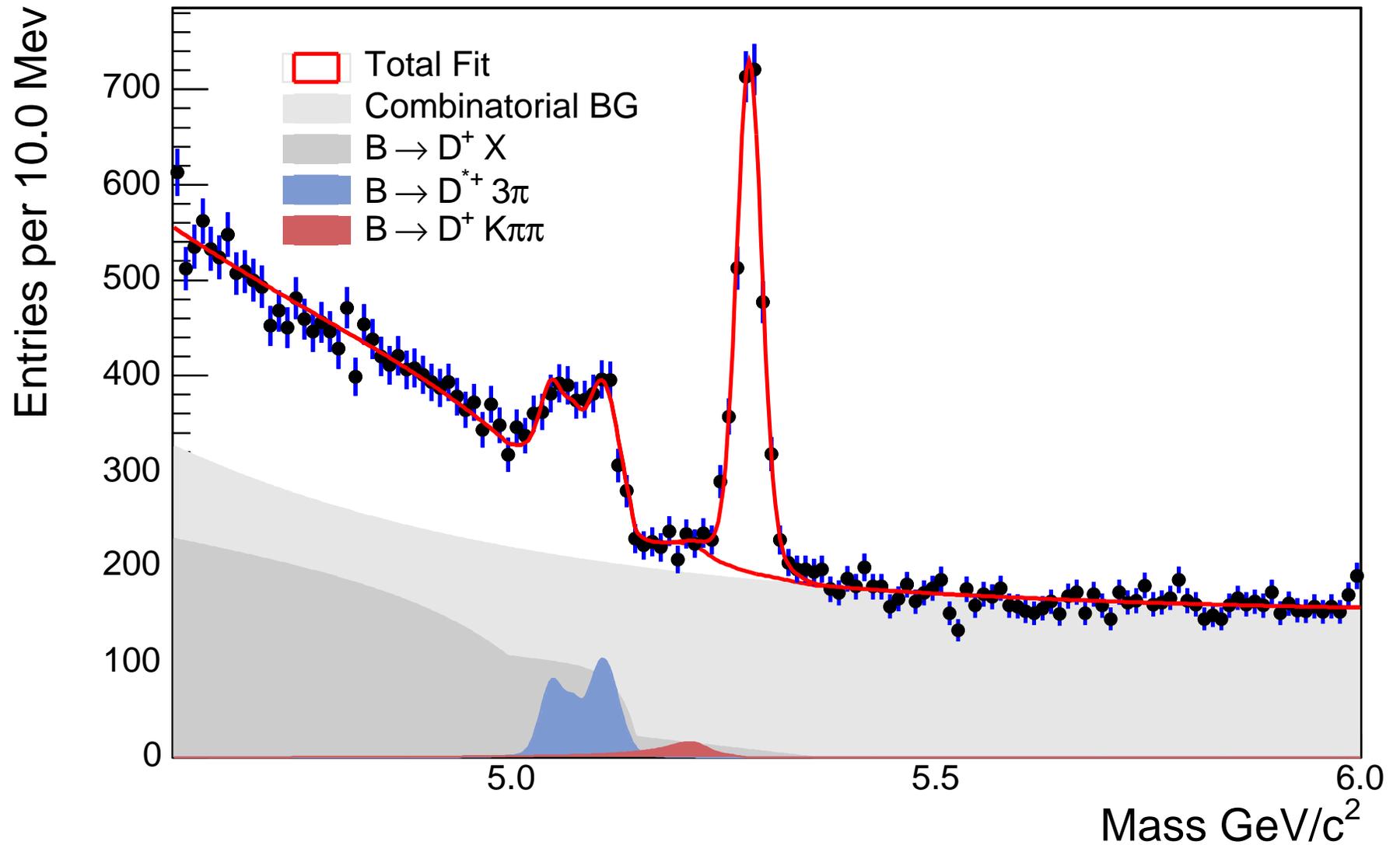
	Cut Variable	Value
$B$	$\frac{L_{xy}}{\sigma(L_{xy})}$	$> 2$
$B$	$d_0$	$< 0.008$ cm
$B$	$\chi_{r\phi}^2$	$< 20$
$D_s$	$\frac{L_{xy}}{\sigma(L_{xy})}$	$> 3$
$D_s$	$L_{xy}^{\leftarrow B}$	$> -0.01$ cm
$D^+$	$\frac{L_{xy}}{\sigma(L_{xy})}$	$> 5$
$D^+$	$L_{xy}^{\leftarrow B}$	$> -0.01$ cm
$\phi$	$M$	[1.01, 1.029]



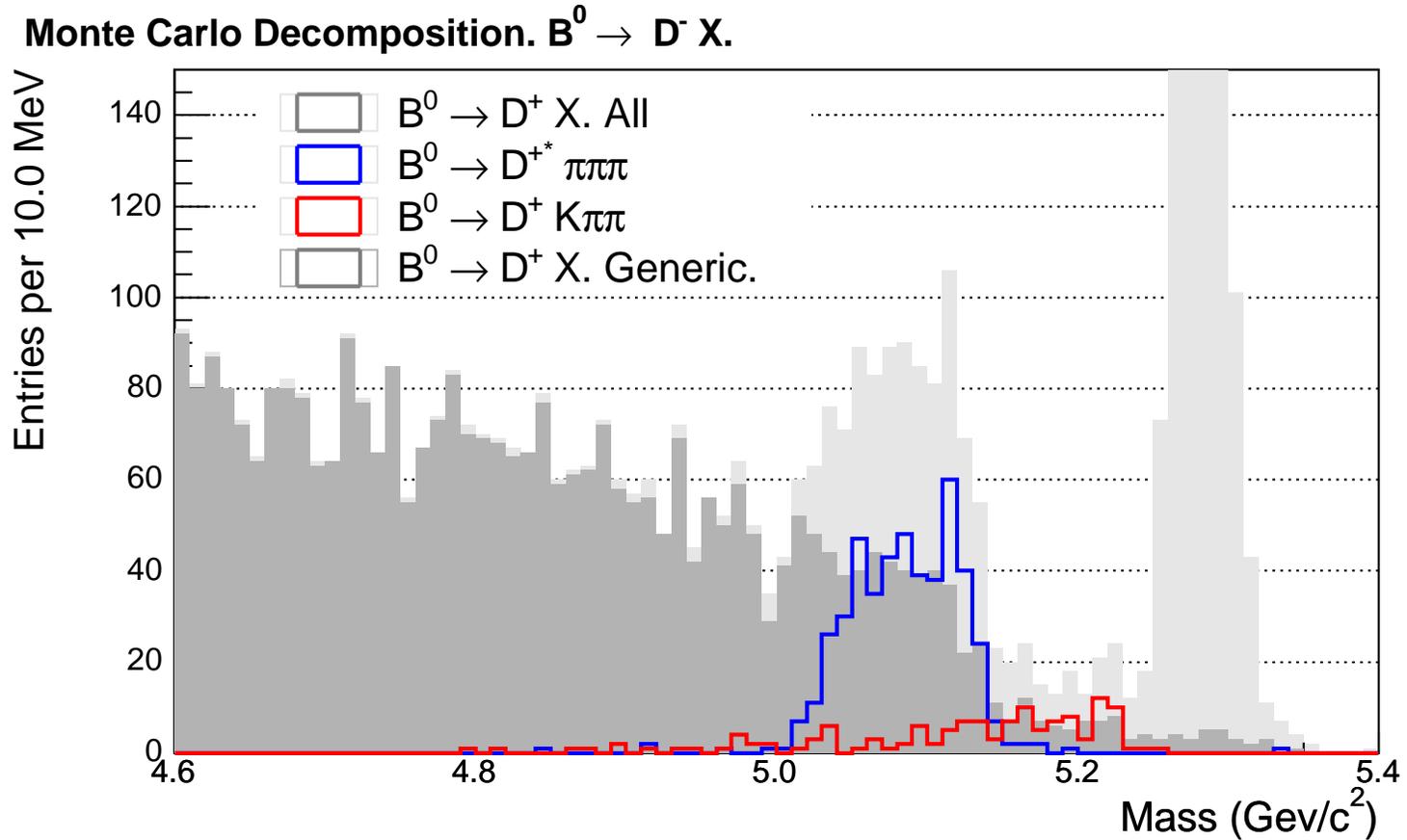
- Optimize  $\frac{S}{\sqrt{S+BG}}$
- Blind signal region while fitting BG
- Use scaled MC to calculate significance

# Final Fit $B^0 \rightarrow D^- 3\pi$

$B^0 \rightarrow D^+ \pi \pi \pi$ . CDF Preliminary.  $243 \text{ pb}^{-1}$ .



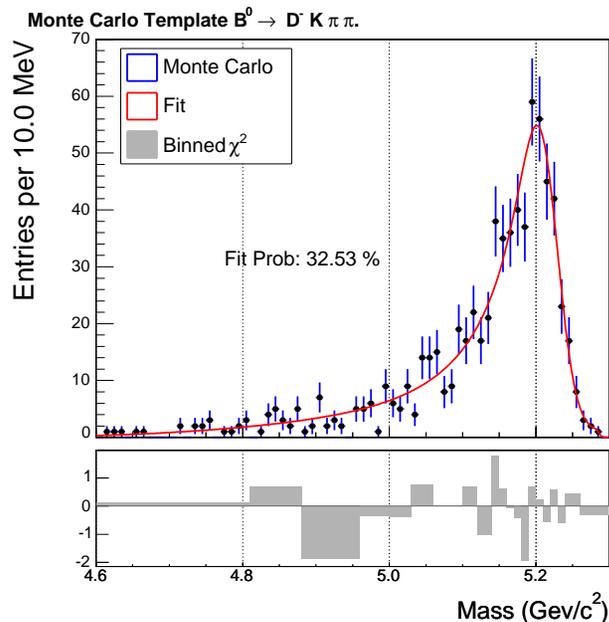
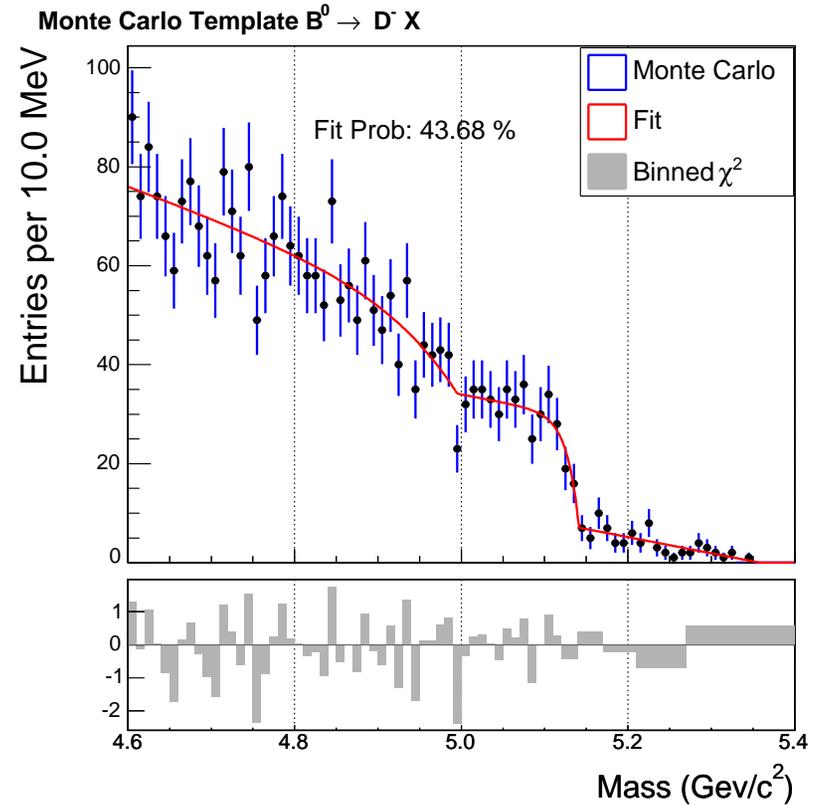
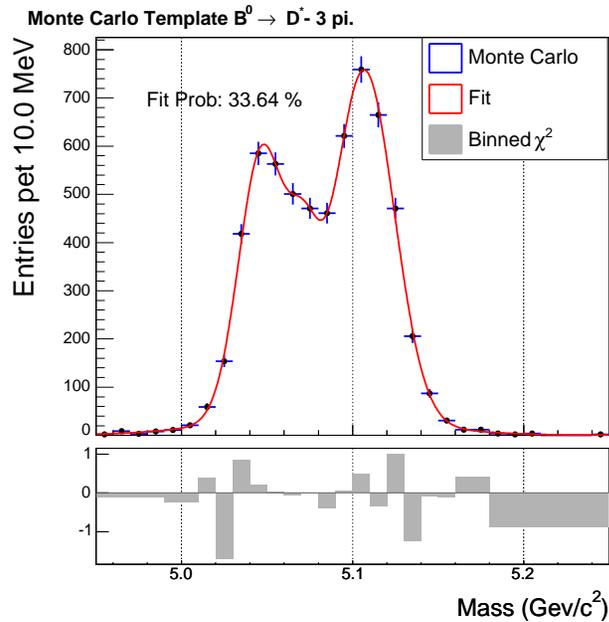
# Physics Background Decomposition $B^0 \rightarrow D^- 3\pi$



## Decompose fitting template into components

- Signal  $B^0 \rightarrow D^- 3\pi$
- $B^0 \rightarrow D^{*-} 3\pi$ ,  $D^{*-} \rightarrow D^- \pi^0$ , - lose  $\pi^0$
- Cabibbo suppressed  $B^0 \rightarrow D^- K \pi \pi$ , - misreconstruct  $K$  as  $\pi$
- The rest  $B^0 \rightarrow D^- X$  (generic)

# Templates For Final Fit $B^0 \rightarrow D^- 3\pi$

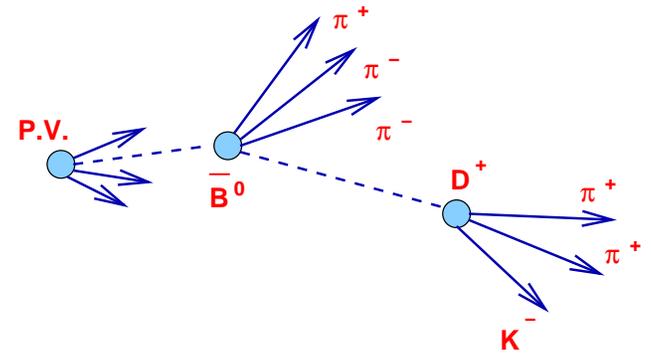
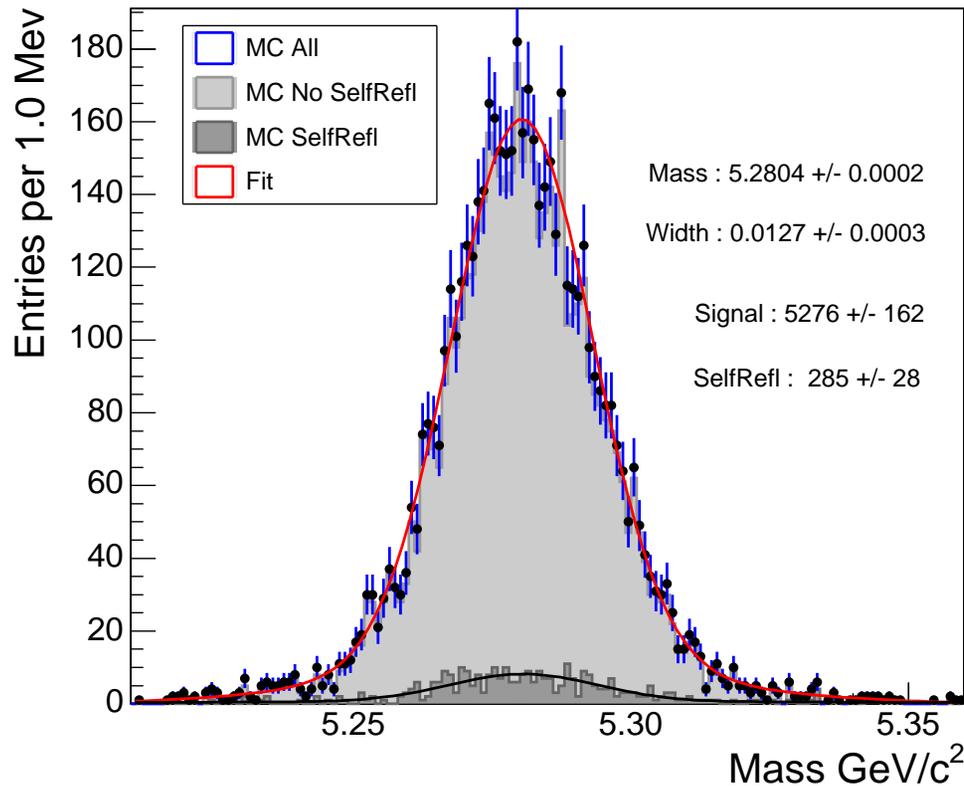


## Monte Carlo Templates

- $B^0 \rightarrow D^{*-} 3\pi, D^{*-} \rightarrow D^- \pi^0$  (lost  $\pi^0$ )
- Cabbibo suppressed  $B^0 \rightarrow D^- K \pi \pi$
- The rest  $B^0 \rightarrow D^- X$  (generic)

# Self Reflections. $B^0 \rightarrow D^- 3\pi$

$B^0 \rightarrow D^+ \pi \pi \pi$ . MC.

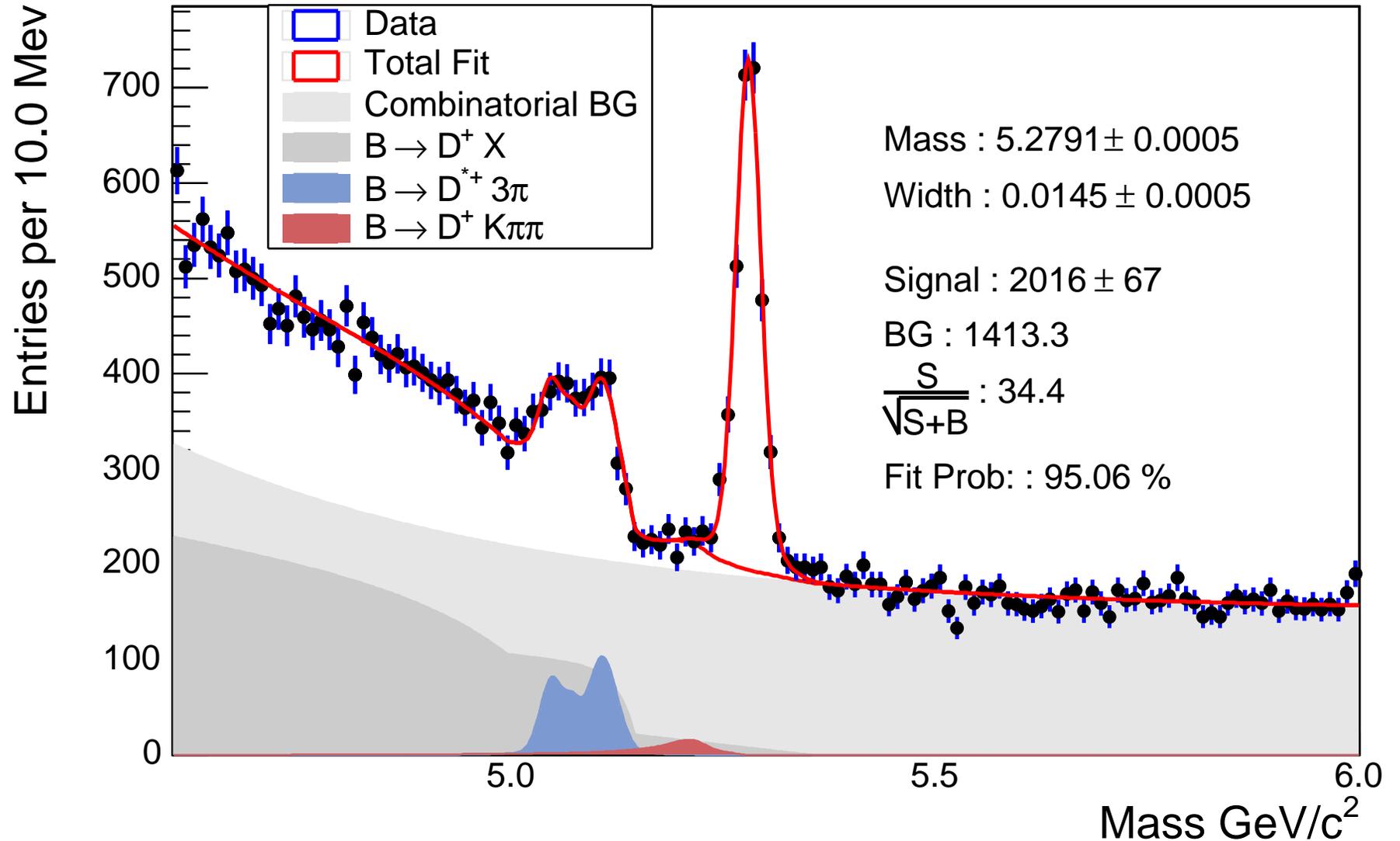


- **Duplicates** - Swap signal track with track from P.V. Mass Distribution is combinatorial.
- **Self-Reflections** - Swap direct pion from  $B$  with pion from  $D$ . **Goes under the signal!**

- $B^0 \rightarrow D^- 3\pi$  is particularly bad due to the lack of constrain on  $3\pi$
- Self-reflection is about 5%
- Resolve by dropping entries with identical track content
- No systematics assigned

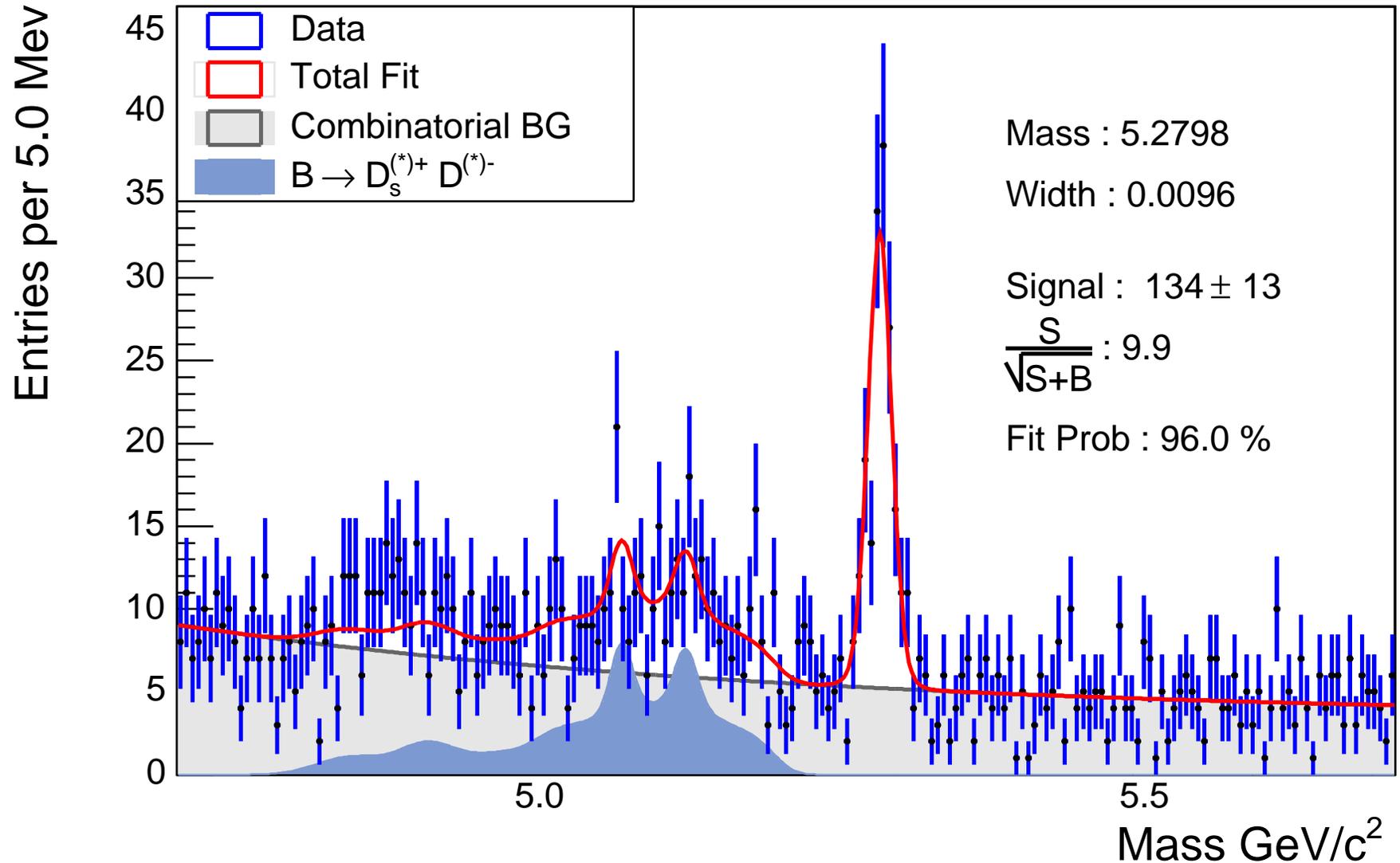
# Final Fit $B^0 \rightarrow D^- 3\pi$

$B^0 \rightarrow D^+ \pi \pi \pi$ . CDF Preliminary.  $243 \text{ pb}^{-1}$ .



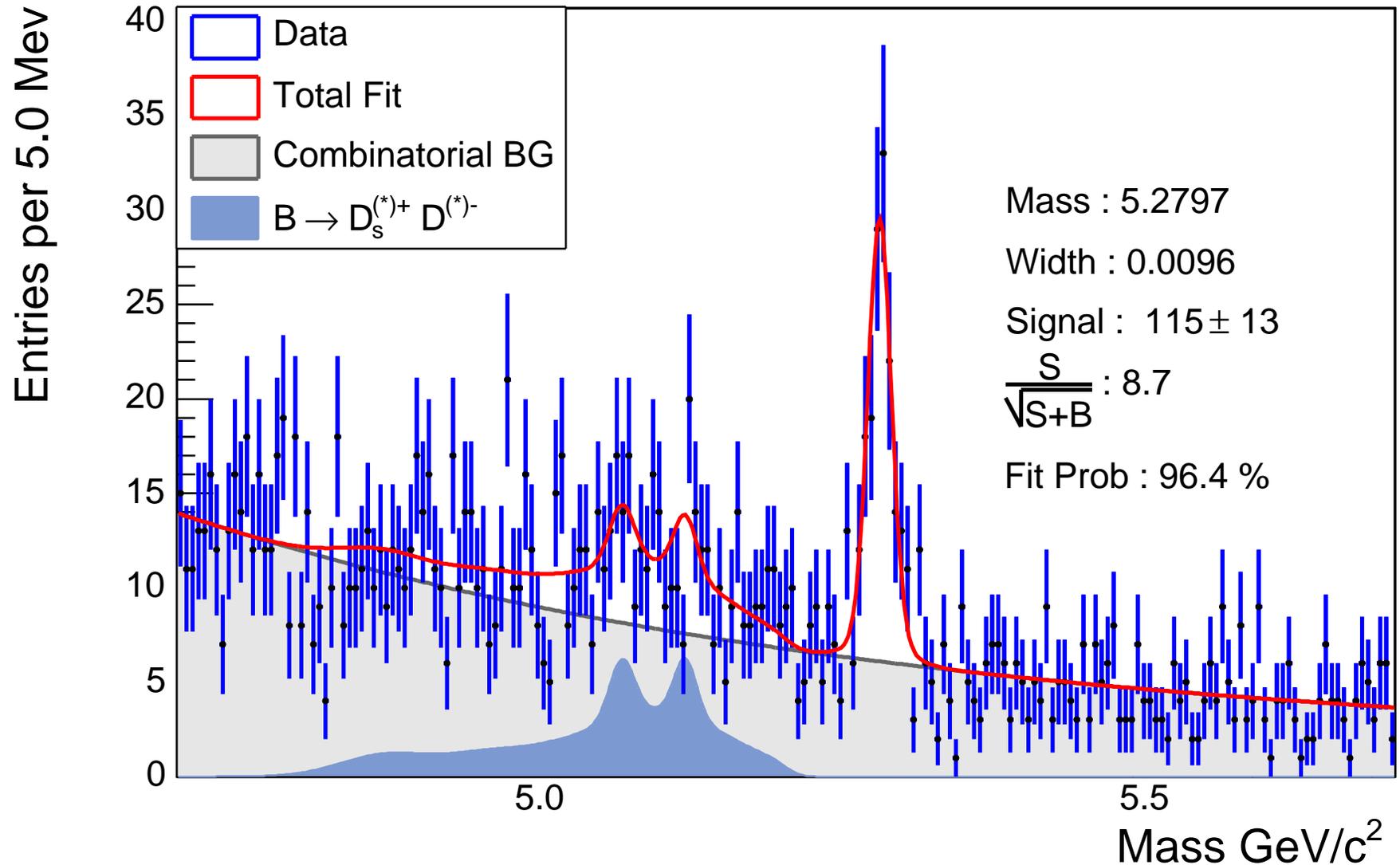
# Final Fit $B^0 \rightarrow D_s^+ D^-$ , $D_s^+ \rightarrow \phi\pi$

$B^0 \rightarrow D_s^- D^+ \rightarrow [\phi\pi][K\pi\pi]$ . CDF Preliminary. 243 pb<sup>-1</sup>



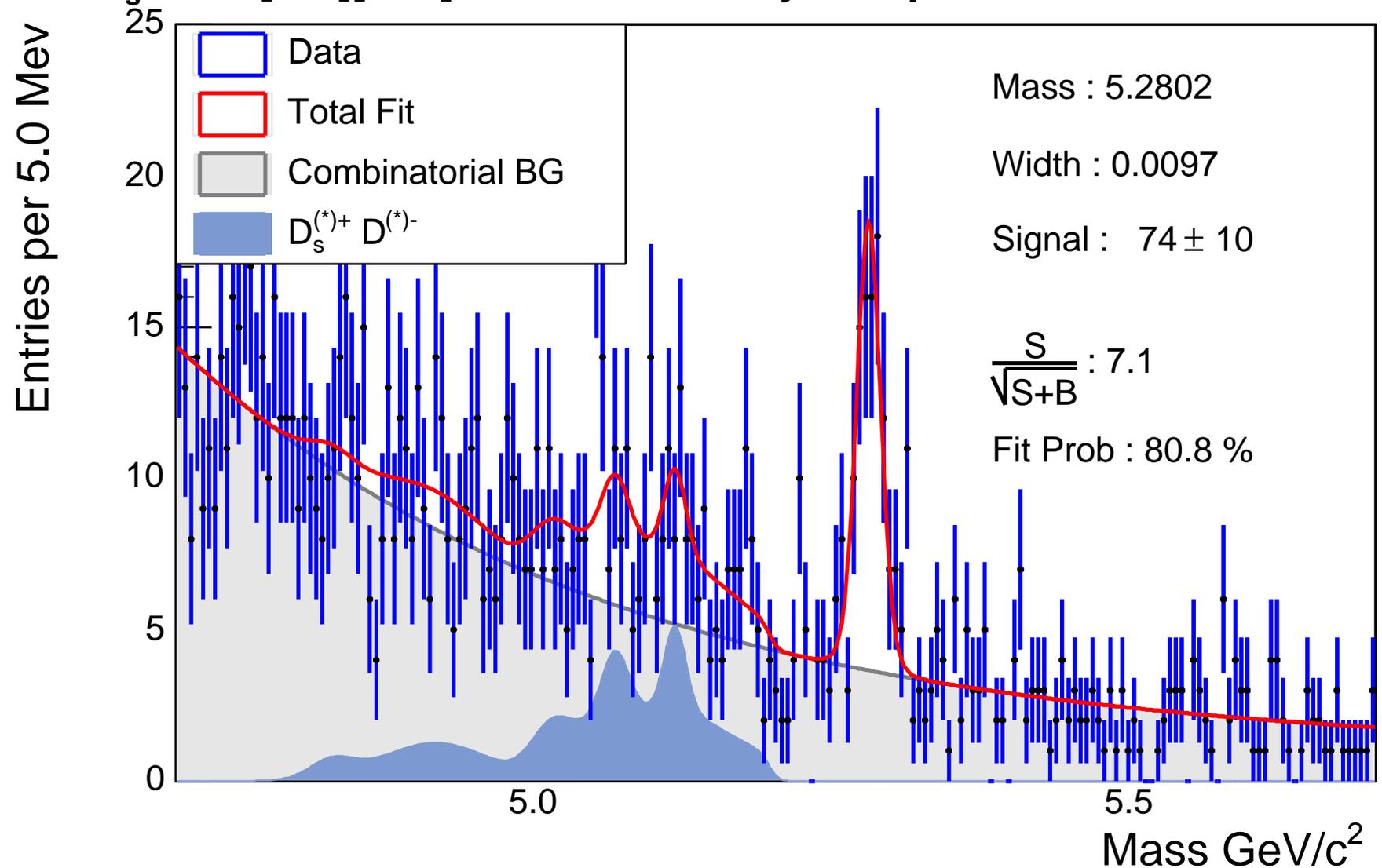
# Final Fit $B^0 \rightarrow D_s^+ D^-$ , $D_s^+ \rightarrow K^* K$

$B^0 \rightarrow D_s^- D^+ \rightarrow [K^* K][K\pi\pi]$ . CDF Preliminary. 243 pb<sup>-1</sup>

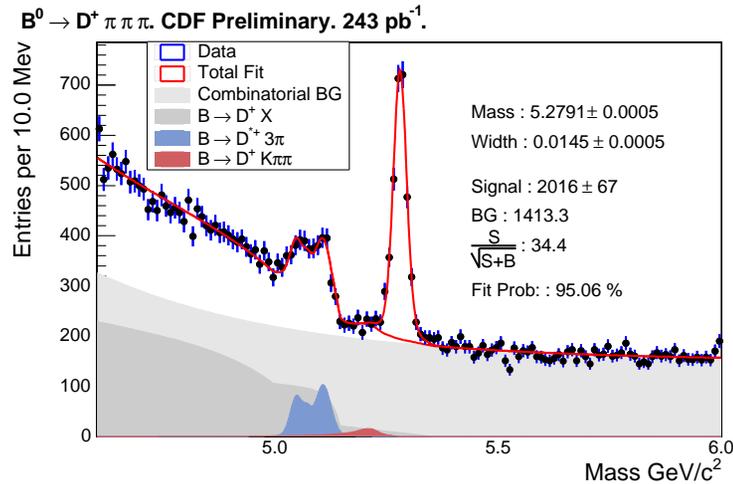


# Final Fit $B^0 \rightarrow D_s^+ D^-$ , $D_s^+ \rightarrow \pi\pi\pi$

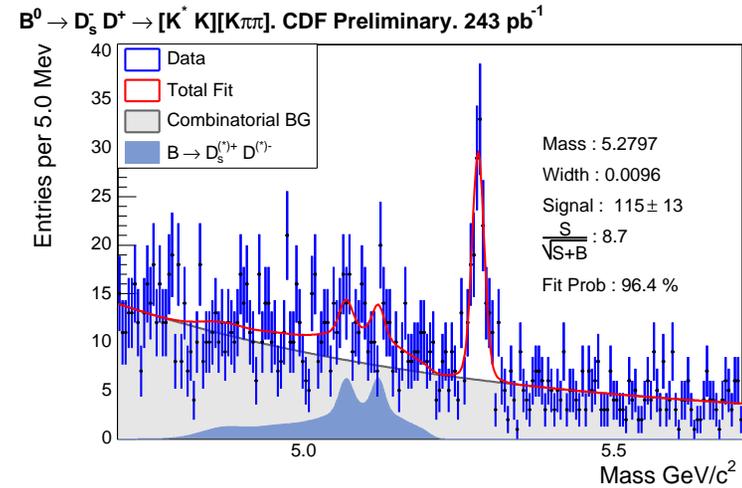
$B^0 \rightarrow D_s^- D^+ \rightarrow [\pi\pi\pi][K\pi\pi]$ . CDF Preliminary.  $243 \text{ pb}^{-1}$ .



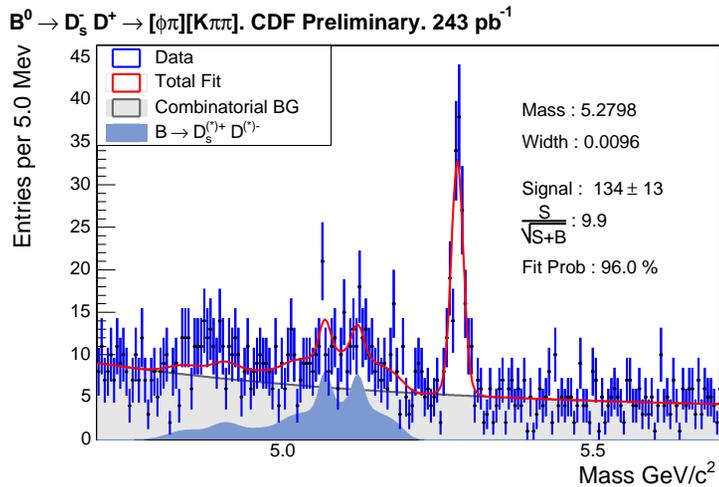
# Compare Yields



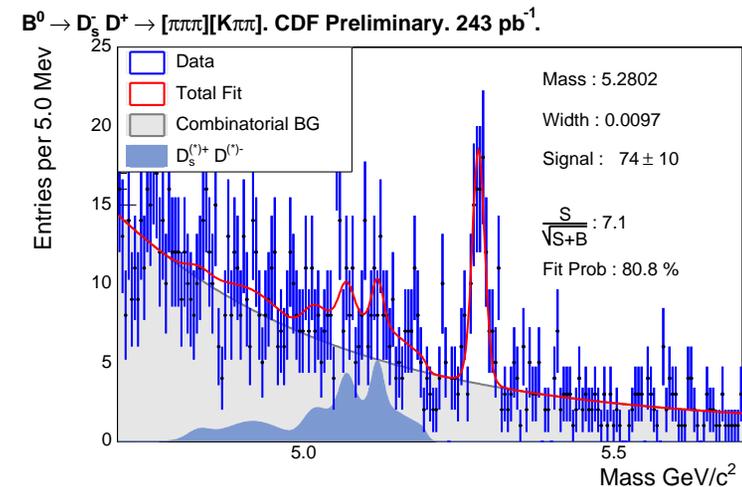
$D^- 3\pi$  Signal:  $2016 \pm 67$



$D_s^+ D^- (K^* K)$  Signal:  $115 \pm 13$



$D_s^+ D^- (\phi\pi)$  Signal:  $134 \pm 13$



$D_s^+ D^- (\pi\pi\pi)$  Signal:  $74 \pm 10$

# Ratios of Branching Fractions

$$\frac{Br(B^0 \rightarrow D_s^+ D^-, D_s \rightarrow \phi \pi)}{Br(B^0 \rightarrow D^- 3\pi)} = 1.95 \pm 0.20(stat) \pm 0.12(syst) \pm 0.49(BR_1)$$

$$\frac{Br(B^0 \rightarrow D_s D^+, D_s \rightarrow K^* K)}{Br(B^0 \rightarrow D^- 3\pi)} = 1.83 \pm 0.22(stat) \pm 0.11(syst) \pm 0.46(BR_1) \pm 0.17(BR_2)$$

$$\frac{Br(B^0 \rightarrow D_s D^+, D_s \rightarrow \pi \pi \pi)}{Br(B^0 \rightarrow D^- 3\pi)} = 2.46 \pm 0.34(stat) \pm 0.17(syst) \pm 0.62(BR_1) \pm 0.34(BR_3)$$

## Branching Uncertainty Summary

- $BR_1$  is due to  $Br(D_s \rightarrow \phi \pi)$
- $BR_2$  is due to  $\frac{Br(D_s \rightarrow K^* K)}{Br(D_s \rightarrow \phi \pi)}$
- $BR_3$  is due to  $\frac{Br(D_s \rightarrow \pi \pi \pi)}{Br(D_s \rightarrow \phi \pi)}$

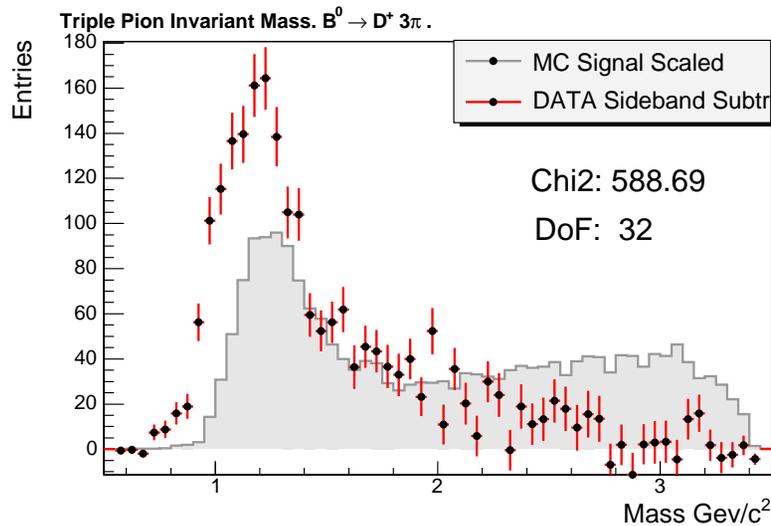
# Systematic Uncertainty Summary

Effect	Syst.[%]
Fit	$\pm 2.00\%$
$3\pi$ Composition	$\pm 3.00\%$
Cut	$\pm 5.0\%$
$D_s D(KK\pi)$ Total Systematics	$\pm 6.2\%$
$D_s D(\pi\pi\pi)$ $D_s$ Composition	$\pm 3.00\%$
$D_s D(\pi\pi\pi)$ Total Systematics	$\pm 6.9\%$

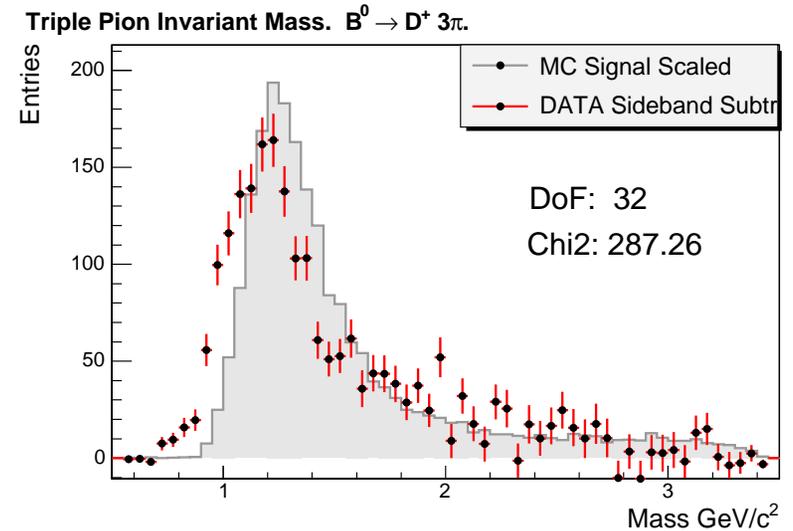
- Fit systematics address instability of the fit and not perfect background model
- $\pi\pi\pi$  composition uncertainty is due to poorly known  $\pi\pi\pi$  subresonance structure.
- Cut systematics due to different behavior of data and MC with respect to cuts
- $D_s \rightarrow 3\pi$  systematics is due to the poorly known  $D_s \rightarrow 3\pi$  composition

# Simulating $3\pi$ Invariant Mass Spectrum for $B^0 \rightarrow D^- 3\pi$

Default decay table



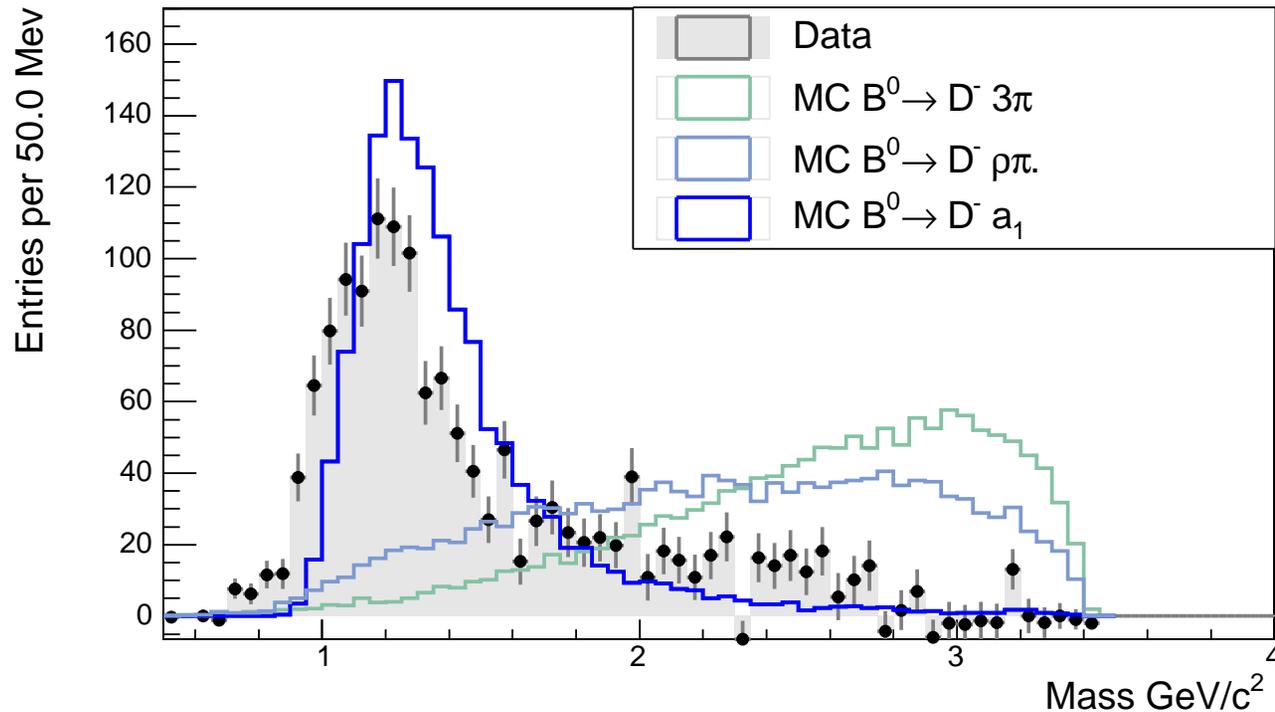
Changed Decay Table.



- Made changes to decay table to make agreement better
- Perfect agreement is not critical - assigned systematics
- $B^0 \rightarrow D^- a_1$  is dominating
- $a_1$  shape is poorly reproduced
- Similar to BaBar result [hep-ex/0409055](http://hep-ex/0409055)

# 3π Subresonance Composition Systematics $B^0 \rightarrow D^- 3\pi$

Three Pion Subresonance Study,  $B^0 \rightarrow D^+ 3\pi$ . CDF Preliminary 243 pb



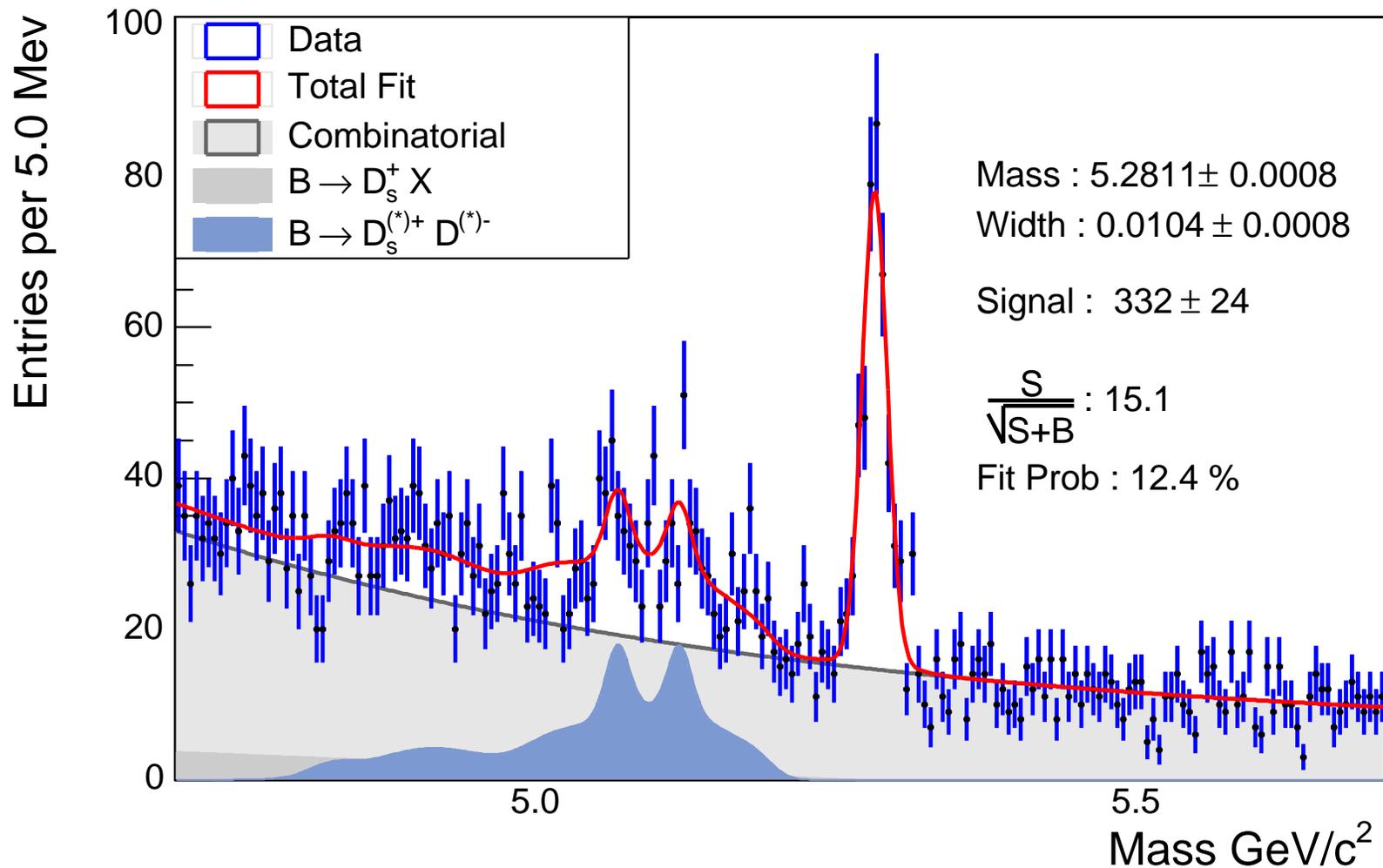
Analysis efficiencies are not the same for different components

	$D^+ a_1$	$D^+ \rho\pi$	$D^+ \pi\pi\pi$
Efficiency $\times 10^3$	$0.225 \pm 0.002$	$0.237 \pm 0.002$	$0.260 \pm 0.002$

Taken into account as systematics

# Combined Fit $B^0 \rightarrow D_s^+ D^-$

$B^0 \rightarrow D_s^- D^+$ . All Channels Combined. CDF Preliminary.  $243 \text{ pb}^{-1}$



Fit is illustrational, - number is not used for final result

# Combined Number

$$\frac{Br(B^0 \rightarrow D_s^+ D^-)}{Br(B^0 \rightarrow D^- 3\pi)} = 2.00 \pm 0.16(NC) \pm 0.12(syst) \pm 0.50(BR_1)$$

Where “NC” - is a combined Non-Correlated uncertainty. It contains

- Statistical error
- Systematics due to  $D_s$  composition in  $D_s D(3\pi) D_s$
- $BR_2$  and  $BR_3$  branching uncertainties due to the ratios of branching fractions.

The error on  $D_s \rightarrow \phi\pi$  branching fraction is dominating

## PDG Result

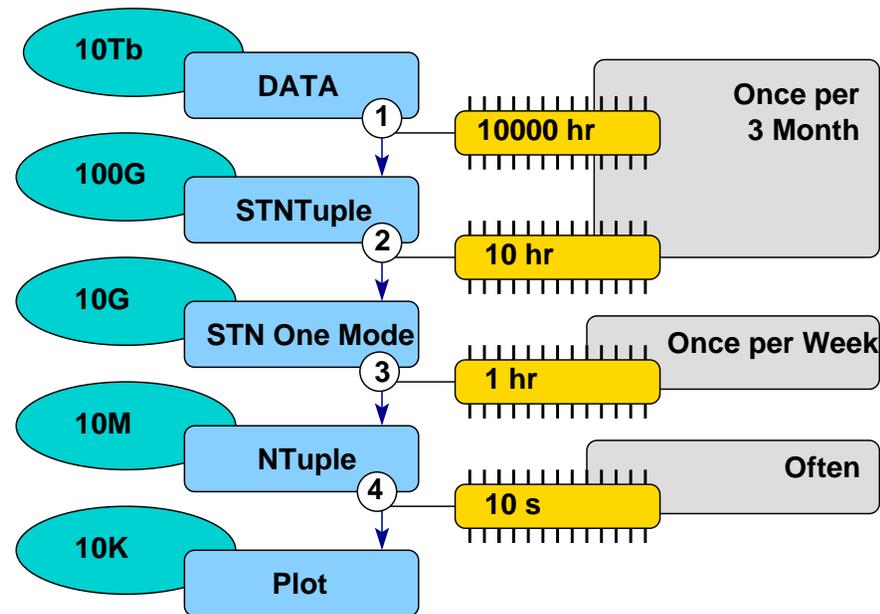
- $Br(B^0 \rightarrow D_s^+ D^-) = (8.0 \pm 3.0) \times 10^{-3}$
- $Br(B^0 \rightarrow D^- 3\pi) = (8.0 \pm 2.5) \times 10^{-3}$

$$\frac{Br(B^0 \rightarrow D_s^+ D^-)}{Br(B^0 \rightarrow D^- 3\pi)} = 1.00 \pm 0.39$$

# Plans

- Finish  $\frac{Br(B_s \rightarrow D_s^- 3\pi)}{Br(B^0 \rightarrow D^- 3\pi)}$
- Use full  $360 pb^{-1}$
- Finish  $\frac{Br(B_s \rightarrow D_s^+ D_s^-)}{Br(B^0 \rightarrow D_s^+ D^-)}$

# Backup Slide Dealing with 10 Tb Data Sample and Combinatorics



1. Reconstruct tens modes at once, save time on subresonances
2. Skim one mode to make smaller input file
3. Skim only variables required for particular study
4. Make an actual plot

6-track modes are very CPU heavy due to high combinatorics